

AD A 044554

(14) FAA-AM-77-13

(6) READABILITY OF ALPHANUMERIC CHARACTERS  
HAVING VARIOUS CONTRAST LEVELS AS A FUNCTION  
OF AGE AND ILLUMINATION MODE

(1) Kenneth W./Welsh,  
Paul G./Rasmussen  
John A./Vaughan

Civil Aeromedical Institute  
Federal Aviation Administration  
Oklahoma City, Oklahoma



(11) July 1977

SEP 27 1977

(13p.)  
Document is available to the public through the  
National Technical Information Service,  
Springfield, Virginia 22161

AD No. \_\_\_\_\_  
DDC FILE COPY

Prepared for  
U.S. DEPARTMENT OF TRANSPORTATION  
Federal Aviation Administration  
Office of Aviation Medicine  
Washington, D.C. 20591

264 320

1B

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

# Technical Report Documentation Page

1. Report No. FAA-AM-77-13 ✓		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle READABILITY OF ALPHANUMERIC CHARACTERS HAVING VARIOUS CONTRAST LEVELS AS A FUNCTION OF AGE AND ILLUMINATION MODE		5. Report Date JULY 1977			
		6. Performing Organization Code			
7. Author(s) K. W. Welsh, P. G. Rasmussen, and J. A. Vaughan		8. Performing Organization Report No.			
9. Performing Organization Name and Address FAA Civil Aeromedical Institute ✓ P. O. Box 25082 Oklahoma City, Oklahoma 73125		10. Work Unit No. (TRAIS)			
		11. Contract or Grant No.			
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591		13. Type of Report and Period Covered			
		14. Sponsoring Agency Code FAA			
15. Supplementary Notes  Work was performed under Task No. AM-D-77-PHY-93.					
16. Abstract <p>Readability data of alphanumeric characters that vary in figure-to-ground contrast ratio were obtained from 36 subjects; 12 subjects were placed in each of three age groups (20-25 yr, 40-45 yr, and 60-65 yr). Minimum illuminance required to identify all contrast combinations was determined at a viewing distance of 40 cm (15.7 in) under dim white and red illumination. Subjects identified all characters while viewing through an artificial pupil (2.0 mm) and, when required, while wearing a spectacle lens correction.</p> <p>Data indicate a significant difference in luminance values for successive changes in contrast ratio under both illumination modes. Under red illumination, threshold luminance values showed a significant trend with age for all five contrast levels. Under white illumination, significant trends were indicated for three of the five contrast levels.</p> <p>With reference to the younger group, individuals in the middle-aged and older groups required an average luminance increase of 18 and 63 percent respectively for equivalent readability scores under white illumination. Under red lighting, corresponding values were 18 and 58 percent.</p>					
17. Key Words Chart readability Luminance threshold Target contrast Effect of age			18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 11	
				22. Price	

READABILITY OF ALPHANUMERIC CHARACTERS HAVING VARIOUS  
CONTRAST LEVELS AS A FUNCTION OF AGE AND ILLUMINATION MODE

I. Introduction.

Alphanumeric symbols on aeronautical charts and other graphic displays are often overprinted on backgrounds that reduce optimal figure-to-ground contrast levels. For example, chart backgrounds are frequently printed with shades of gray or other colors to depict water or terrain elevation. In addition, alphanumeric symbols that are screened (contain small white dots) cause a further reduction in target contrast. An early investigation by Ludvigh (1) indicated that visual acuity remained relatively constant for contrast levels greater than 30 percent but decreased rapidly as contrast dropped below this value. Results of a recent study (2) conducted by the authors indicated, but did not define, the role of contrast ratio in determining readability of characters printed on aeronautical instrument approach charts (National Ocean Survey and Jeppesen Company). To expand the existing data base in this area, we conducted a study designed to assess minimum illumination required to identify black alphanumeric characters presented on gray background materials that alter contrast ratio in equal increments. Additional parameters evaluated were the effects of age on readability under dim red and white illumination. Assessment of neuroretinal sensitivity among individuals in younger, middle-aged, and older groups required the use of an artificial pupil to avoid normal variations in pupil size.

These data, when combined with those of other investigators, are necessary to specify minimum contrast ratios acceptable to all chart users under viewing conditions that may include night flying operations and air traffic control activities.

II. Methods.

To obtain approximately equal contrast increments, we measured 15 shades of neutral gray paper (Pantone, Inc.) for reflective brightness under 50 fL of white incandescent lighting. Ratios between all shades of gray and the black alphanumeric characters (2.1 fL) were plotted, from which five shades were selected for evaluation (Figure 1). Gray background materials selected for the display included Pantone Nos. 422, 428, 430, 432, and 441 for contrast ratios of 9.3:1, 12.8:1, 6.6:1, 3.2:1, and 16.2:1 respectively. Contrast notations refer to the differences in brightness between the background and black test

Section ☒ 6  
Other ☐  
☐

6. CONTROL, AVAILABILITY CODES

Dim. Avail. 352, 4 SPECIAL

HA

characters. For example, if the brightness of the background and test characters are 13.8 and 2.1 fL respectively, the ratio is shown as 6.6:1.

Test characters were 8-point futura demibold (Chartpak) measuring 1.9 mm high, 1.0 to 1.9 mm wide, and 0.35 to 0.40 mm stroke width. Characters selected for evaluation included numerals 2 through 9 and letters B through H, P, R, S, Y, and Z. A spacing of 3.5 mm was used between adjacent characters.

Four different but equivalent lists were prepared on each of the selected background panels. Each list was composed of five lines of four characters each. All 20 characters selected for the study appeared only once in each list. The lists were then mounted in columns on the display drum so that each column contained one each of the five different contrast panels, but in different sequences, to allow control of position effects. A multiple-detent system was used to align each row of characters with the central viewing aperture in the occluder plate during manual rotation of the display drum.

The illumination system consisted of a frosted white incandescent bulb (GE, 100 W) positioned as shown in Figure 2. Illumination was directed toward the target area through a circular aperture 3.0 cm (1.2 in) in diameter in a metal enclosure surrounding the bulb. To obtain threshold luminance data for each contrast level, the experimenter operated a variable power source to increase illumination on the test characters and surrounding area. However, to operate the light at or near the specified voltage (120 V) and color temperature, yet still obtain dim illumination levels on the target, the experimenter placed a neutral density filter between the light source and the target. Using data from preliminary testing, the operator selected a filter (1.0, 5.0, or 9.5 percent transmission) prior to beginning each contrast level that allowed threshold readability to occur within the desired voltage range (90 - 130 V). This system operated independently from photometer (luminance) measurements that were taken directly from the target area.

Red illumination on the target was obtained by placing a Wratten No. 25 (tricolor) filter into the light path. All filters could be interchanged rapidly by a manually operated slide holder.

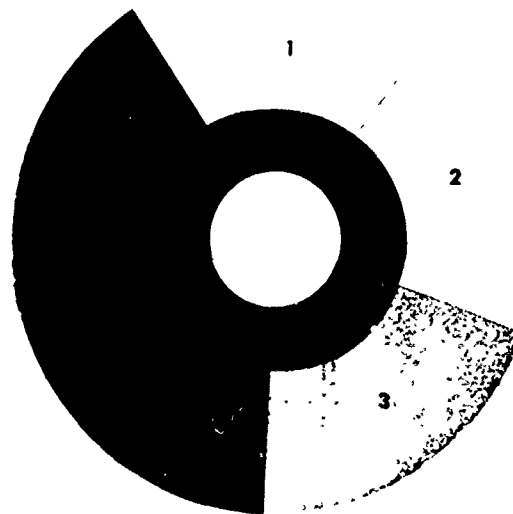


Figure 1. Photographic reproduction of the five gray background materials used in the study. Measured contrast ratio values for each sector are (1) 16.2:1, (2) 12.8:1, (3) 9.3:1, (4) 6.6:1, and (5) 3.2:1.

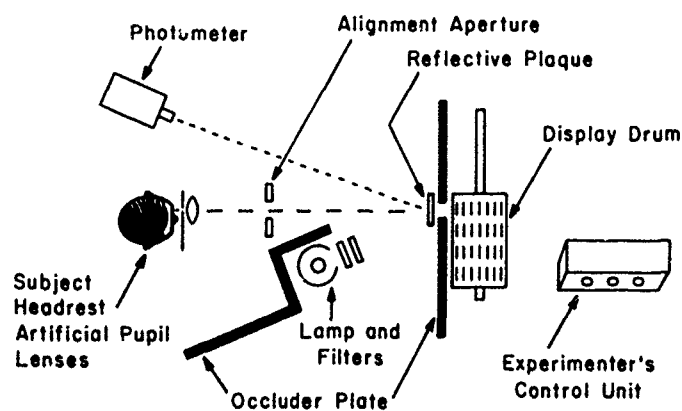


Figure 2. Diagram showing relative location of display, illumination, and recording apparatus.

The minimum luminance level required to identify the test characters was measured with a photometer (Pritchard Spectra, 1970 PR) located near the subject's left shoulder. The photometer was directed toward a small white reflectance plaque located immediately below the viewing aperture in the occluder plate as shown in Figure 2. To correct the photometer readings taken from an oblique angle  $22^{\circ}$  to the subject's line-of-sight, the experimenter obtained a correction factor and applied it to all photometer readings. The correction factor was found by taking a series of readings from both angles (oblique and perpendicular to the surface of the plaque) under a variety of luminance conditions. These readings were found to be consistent at each location and amounted to a 14-percent reduction in all luminance measurements.

The subject population was divided into three groups of 12 each as follows: (i) a younger group with a mean age of 22.9 years, range 20-25; (ii) a middle-aged group with a mean age of 43.6 years, range 40-46; and (iii) an older group with a mean age of 63.8 years, range 60-70. Prior to testing, each subject was given a complete visual examination.

Each subject was tested monocularly by using the eye with the lowest ocular refractive error. This method was used to minimize the thickness of the lens and increase light transmission into the eye. Any subject not requiring a prescription lens wore a plano (0.0 D) lens in the trial frame. Located behind either the plano or prescription lens was a 2.0-mm artificial pupil centered in the trial frame to match the visual axis of the eye. The opposite eye was occluded during the testing period.

A forehead rest located 40 cm (15.7 in) from the target and a circular alignment aperture 2.0 cm (0.78 in) in diameter standardized the distance and viewing angle for all subjects. Following a brief demonstration of the experimental procedure and a 10-min dark-adaptation period, the illumination in the test area was raised gradually until the subject correctly identified all four alphanumeric characters. The luminance value was recorded and the light on the test characters was dimmed for approximately 10 s prior to the next trial. Approximately 45 min, including a 5-min rest period, were required to obtain threshold luminance values for all contrast levels and both illumination modes. Eight additional minutes were required to obtain a dark adaptation profile curve on each

subject. These measurements, obtained with a Goldmann-Weekers adaptometer, were compared to population norms to rule out abnormal dark adaption processes that may affect visual performance under mesopic illumination levels.

### III. Results.

To minimize variability for different target contrast levels and thus facilitate statistical comparisons, we translated the means of the five determinations (20 characters) made by each subject at each contrast level into their base 10 log values. The data points appearing in Figure 3 for the white illumination trials and Figure 4 for the red illumination trials are the means of these log values.

Data indicate a significant difference ( $P < .01$ ) in luminance values for successive changes in contrast ratio for both illumination modes.

To evaluate differences in lighting requirements between the three age groups, we made tests for linear trend for each contrast level and illumination mode. Under white illumination, statistically significant F-values were found across age groups for three of the five contrast levels. Significant trends indicating more illumination with increasing age occurred at the 0.05 level for contrast ratios 9.3:1 and 6.6:1, while the lowest contrast ratio (3.2:1) was significant at the 0.01 level. Under red illumination, a linear trend with age was indicated for all contrast levels. Values of  $F$  at the 0.05 level were found for contrast levels 12.8:1 and 3.2:1; the remaining contrast levels were significant at the 0.01 level. These trends are indicated graphically in Figures 3 and 4.

Table 1 shows the illumination required by the older and middle-aged groups as a percentage of the younger age group (20-25 yr) for each of the five contrast levels.

### IV. Discussion.

To observe the effects of contrast ratio variations within each age group, we held constant the following parameters: (i) target size, (ii) viewing distance, (iii) visual acuity, and (iv) pupil size. The dark adaptation state of the subjects could not be precisely controlled during the testing period because illumination requirements varied between contrast



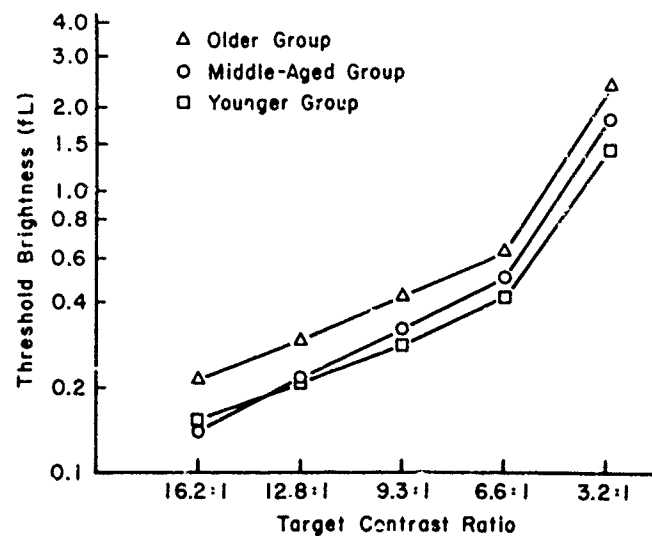


Figure 3. Luminance values measured from a reflectance plaque for threshold readability under white illumination for all contrast ratios and age groups.

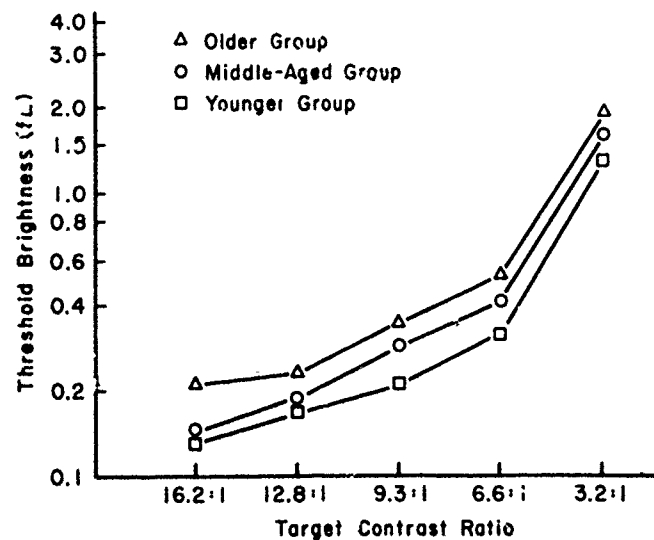


Figure 4. Luminance values measured from a reflectance plaque for threshold readability under red illumination for all contrast ratios and age groups.

levels of the characters (five levels), and prolonged readaptation periods between presentations were impractical. However, results from dark adaptation measurements taken immediately after the test period indicate a stable mesopic adaptative state was maintained during testing.

TABLE 1. Percentage Increase in Illumination Required by Middle-Aged and Older Individuals with Reference to Younger Group

Contrast Ratio	Red		White	
	Mid	Old	Mid	Old
3 2:1	21.7%	48.2%	40.2%	94.0%
6.6:1	27.4%	65.4%	27.1%	62.5%
9.3:1	16.6%	66.4%	23.0%	60.7%
12.8:1	11.4%	42.9%	3.2%	46.5%
16.2:1	14.0%	69.9%	-1.9%	49.7%

Trendelenburg (3) has shown that pupil size decreases with age under either bright or dim illumination conditions. In addition, pupil size varies within age groups and with the ambient luminance condition. Shlaer (4) indicated that pupil size has a direct bearing on visual acuity at low luminance levels and must be controlled by an artificial pupil or with a Maxwellian viewing system described by Westheimer (5). Equalizing pupil size was, therefore, considered necessary to assess neuroretinal sensitivity among the three age groups. Our results, however, if obtained without the use of an artificial pupil, would be expected to show a proportionally larger decrease in luminance for threshold readability for younger subjects with larger pupils than for older subjects. Light transmission and scattering properties of the intraocular media were not obtained but may account partially for the threshold variations occurring among the three age groups.

Photometric values for threshold luminance, obtained under red and white illumination, should be considered with respect to the sensitivity of the photomultiplier tube within the photometer, which is corrected to match the retinal sensitivity curve of the standard human observer. As such, the photometer is maximally sensitive to energy from the central portion of the visible spectrum and decreases in sensitivity toward the red and blue ends.

Luckiesh and Taylor (6) reported that visual acuity is dependent on the color of the light source at brightness levels below 0.05 fL. They indicate that red light provides the best visual resolution followed by daylight tungsten, gold, green, and blue. A comprehensive discussion of these and other factors controlling visual performance can be obtained from several sources (7, 8, 9, 10).

Our data show a significant increase in illumination was required for each successive decrease in contrast ratio for all age groups and for both illumination modes. Under red illumination, a significant trend for increased brightness with age was found for all target contrast levels. Under white (broadband) illumination, significant trends among age groups were found for three of five contrast levels. In addition, significant trends with age were indicated at the 0.01 level for three contrast levels under red lighting and one contrast level for white illumination. These findings seem to indicate that age may be a more important factor in threshold readability under red rather than white illumination.

Other investigators who have evaluated the effects of contrast ratio on visual performance include Blackwell (11), who used circular discs at 19.2 m (63 ft); Mourtant and Langolf (12), white letters on gray backgrounds at 0.8 m (32 in); Richards (13), gray letters on a white background at 6 m (20 ft); and Williams (14), digits having nine contrast levels at 0.76 m (30 in). None of the above evaluated performance under red illumination or with pupil size controlled. Measuring response time (11, 12, 14) and visual acuity (1, 13), these investigators determined the following: (i) visual acuity improved and response time decreased with increasing contrast between the target and the background; (ii) visual acuity improved and response time decreased with increasing ambient illumination; and (iii) contrast ratio had a greater influence on visual performance under dim rather than bright illumination.

Several investigators (12, 13) have sought to determine the effect of age on recognition of characters having various contrast levels. However, none of these investigators equalized pupil size or corrected visual acuity completely with lenses for the viewing distance. Their data, although realistic and predictive of the population at large, are limited when comparisons of neuroretinal sensitivity are made among age groups, albeit their data under white illumination indicate a progressive decrease in performance with age at scotopic luminance levels. Our data indicate that additional illumination is required with increasing age, although only under red lighting are significant increases required for most contrast levels.

Guth (15), using one contrast level (black on white, 6-point type at 76 cm), found that illumination required for fixed readability values increased gradually up to the fourth decade and more rapidly thereafter. Ferree et al. (16), presenting Landolt Ring targets (black on white), also found that older individuals require additional illumination and that visibility of small targets reaches a maximum at levels of 10 and 20 fc for younger and older subjects respectively.

Rock (17) investigated the effect of dim illumination on other visual attributes, including depth perception, absolute motion threshold, the Muller-Lyer illusion, and a simple addition task.

#### V. Summary.

The minimum illumination required to identify black alphanumeric characters on gray background materials selected to provide a broad range of contrast levels was determined for three age groups (mean ages 22.9, 43.6, and 63.8).

Data indicate that significant increases in luminance were required for decreasing contrast levels under both illumination modes, red and white. Under red illumination, a significant trend in brightness with age was indicated for all five contrast levels. Under white illumination, a significant trend was noted for three of the contrast levels.

#### REFERENCES

1. Ludvigh, E.: Effect of Reduced Contrast on Visual Acuity as Measured with Snellen Test Letters, ARCH. OPHTHALMOL. 25:469-474, 1941.
2. Welsh, K. W., J. A. Vaughan, and P. G. Rasmussen: Readability of Approach Charts as a Function of Visual Acuity, Luminance, and Printing Format, AVIAT. SPACE ENVIRON. MED. 47:1027-1031, 1976.
3. Trendelenburg, W.: Der Gesichtssinn, 2d ed., Berlin, Springer-Verlag, 1961.
4. Schlaer, S.: The Relation Between Visual Acuity and Illumination, J. GEN. PHYSIOL. 21:165-188, 1937.
5. Westheimer, G.: The Maxwellian View, VISION RES. 6:669-682, 1966.
6. Luckiesh, M., and A. H. Taylor: A Summary of Researches in Seeing at Low Brightness Levels, ILLUM. ENG. 38:189-207, 1943.
7. Graham, C. H.: Vision and Visual Perception, New York, John Wiley and Sons, Inc., 1966, pp. 321-349.
8. Watlins, R. D.: The Presentation of Printed Information to Aircraft Pilots, Aviation Medical Branch, Department of Civil Aviation, Aviation Medicine Memorandum No. 27, Melbourne, Australia, 1970.
9. Weale, R. A.: The Aging Eye, New York, Harper and Row, 1963.
10. Wulfeck, J. W., A. Weisz, and M. W. Raben: Vision in Military Aviation, Wright Air Development Center Technical Report No. 58-399, Wright-Patterson Air Force Base, Ohio, 1958.
11. Blackwell, H. R.: Visual Basis of Desirable Standards of Quantity and Quality of Illumination, AM. J. OPTOM. 40:581-613, 1963.
12. Mourant, R. R., and G. Langolf: Luminance Specifications for Automobile Instrument Panels, HUM. FACTORS 18:71-84, 1976.

13. Richards, O. W.: Effects of Luminance and Contrast on Visual Acuity, Ages 16 to 90 Years, AM. J. OPTOM. PHYSIOL. OPTICS 54:178-184, 1977.
14. Williams, C. M.: Legibility of Numbers as a Function of Contrast and Illumination, HUM. FACTORS 9:455-460, 1967.
15. Guth, S. K.: Effects of Age on Visibility, AM. J. OPTOM. 34:463-477, 1957.
16. Ferree, C. E., G. Rand, and E. F. Lewis: The Effect of Intensity of Light on the Visual Acuity of Presbyopic and Non-presbyopic Eyes, TRANS. ILLUM. ENG. SOC. 29:296-313, 1934.
17. Rock, M. L.: Visual Performance as a Function of Low Photopic Brightness Levels, J. APPL. PSYCHOL. 37:412-427, 1953.